

18. CORRESPONDENCE ADDRESS

Customer Number or Bar Code Label

(Insert Customer No. or Attach bar code label here)

or Correspondence address below

NAME	Barbara A. Gyure				
	American Home Products Corporation				
ADDRESS	Patent & Trademark Office - 2B (Attn: Kay E. Brady)				
	One Campus Drive				
CITY	Parsippany	STATE	NJ	ZIP CODE	07054
COUNTRY	U.S.A.	TELEPHONE	(617) 665-8653		FAX (617) 876-5851

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Typed or printed name	Barbara A. Gyure		
Signature	<i>Barbara A. Gyure</i>	Date	January 28, 2000

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicants : Zhang *et al.*
Serial No. : Not yet assigned Examiner: Not yet assigned
Filed : January 28, 2000 Art Unit: Not yet assigned
For : Methods and Compositions for Healing and Repair of Articular Cartilage

Honorable Assistant Commissioner for Patents
Washington, D.C. 20231
BOX: PATENT APPLICATION

LETTER UNDER 37 CFR §1.63

Pursuant to 37 CFR §1.63, the enclosed application is being filed without a signed Oath or Declaration for the purpose of obtaining a filing date. Upon notification by the United States Patent and Trademark Office, Applicants will submit an executed Declaration and Power of Attorney within the period specified and pay the requisite fee.

SUBMITTED IN TRIPPLICATE

Respectfully submitted,

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Alison M. Flippinbottom

Barbara A. Gyure
Barbara A. Gyure
Reg. No. 34,614
Attorney of Record

LEGAL AFFAIRS
American Home Products Corporation
One Campus Drive
Parsippany, New Jersey 07054
Telephone: (617) 665-8653
Facsimile: (617) 876-5851
Dated: January 28, 2000

Inventor Information

GI 5340A

Inventor One Given Name :: Renwen
Family Name :: Zhang
Postal Address Line One :: 359 Veterans Blvd.
City :: Rutherford
State or Province :: New Jersey
Country :: USA
Postal or Zip Code :: 07070
City of Residence :: Rutherford
State or Prov. of Residence :: New Jersey
Country of Residence :: USA
Citizenship Country:: USA

Inventor Two Given Name :: Diane
Family Name :: Peluso
Postal Address Line One :: 107 Emery Road
City :: Marshfield
State or Province :: Massachusetts
Country :: USA
Postal or Zip Code :: 02050
City of Residence :: Marshfield
State or Prov. of Residence :: Massachusetts
Country of Residence :: USA
Citizenship Country :: USA

Inventor Three Given Name :: Elisabeth
Family Name :: Morris
Postal Address Line One :: 15 Apple Street
City :: Sherborn
State or Province :: Massachusetts
Country :: USA
Postal or Zip Code :: 01770
City of Residence :: Sherborn
State or Prov. of Residence :: Massachusetts
Country of Residence :: USA
Citizenship Country :: USA

Correspondence Information

Correspondence Customer Number ::

Name Line One :: American Home Products Corporation
Name Line Two :: Patent & Trademark Department - 2B
Address Line One :: Attn: Barbara A. Gyure
Address Line Two :: One Campus Drive
City :: Parsippany
State or Province :: New Jersey
Country :: USA
Postal or Zip Code :: 07054
Telephone :: (617) 665-8653
Fax :: (617) 876-5851

Application Information

Title Line One ::

Methods and Compositions for Healing and
Repair of Articular Cartilage

Title Line Two::

0

Total Drawing Sheets ::

N

Formal Drawings? ::

Utility

Application Type ::

GI 5340A

Docket Number ::

Licensed US Govt. Agency ::

Contract or Grant Numbers ::

Secrecy Order in Parent Appl.? ::

Representative Information

Representative Customer Number ::

Registration Number One :: 41,323

Registration Number Two :: 34,614

Registration Number Three :: 34,614

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Asim M. Hisham
Name of Signing Person

GI 5340A

METHODS AND COMPOSITIONS FOR HEALING AND REPAIR OF ARTICULAR CARTILAGE

FIELD OF THE INVENTION

5 The present invention relates to the field of tissue repair, specifically, the regeneration of stable and functional articular cartilage repair. Thus, the present invention may be useful in reconstructive surgery or other procedures for the regeneration or repair of articular cartilage.

BACKGROUND OF THE INVENTION

10 The repair of articular cartilage injuries remains a challenge in present day orthopedics. Several of the current therapeutic strategies are based upon the grafting of chondral and osteochondral tissues. Autologous osteochondral grafting provides the most appropriate physiological material. However, donor tissue is limited, and often requires surgery at a secondary site in order to harvest tissue for transplant. Accordingly, despite 15 substantial endeavors in this field, there remains a need for an effective method of repair of articular cartilage defects and injuries which provides appropriate physiological repair without the need to collect autologous tissue from the patient.

SUMMARY OF THE INVENTION

20 The present invention provides methods and compositions for regenerating functional and physiologically appropriate tissue repair for the repair of articular cartilage injuries and defects. In particular, the present invention comprises methods of treating patients with articular cartilage injuries or defects. The methods and compositions of the present invention are advantageous in that they utilize bone morphogenetic proteins (BMPs), which are known to have osteogenic and/or chondrogenic properties, and which 25 may be produced via recombinant DNA technology, and therefore are of potentially unlimited supply. The methods and compositions of the present invention are further advantageous in that regeneration of functional articular cartilage may be accelerated or

5 may be of greater ultimate strength and stability, and the tissue formed at the site of the defect or injury is physiologically appropriate.

The use of BMP to augment the repair of articular cartilage defects and injuries may result in better methods for treatment of osteoarthritis, thus obviating, delaying or reducing the need for artificial hip replacements and other common interventions.

10 Preclinical evaluations indicate that rhBMP-2 improves early healing of full thickness defects of articular cartilage in rabbits.

DETAILED DESCRIPTION OF THE INVENTION

According to the present invention, methods and compositions are provided for treatment of patients who suffer from some form of articular cartilage injury or defect.

15 The injury may be the result of acute stress, or injury, such as resulting from participation in athletics, or from accidental occurrences which tear, mar or otherwise injure the articular cartilage.

20 The methods and composition are advantageous in that repair or improvement of articular cartilage defects, particularly full thickness articular cartilage defects. Other defects may also be treated by the methods and compositions of the present invention, particularly with an additional procedure in which the site of the defect is further aggravated so as to reach the underlying subchondral bone.

25 In the present invention, active growth factor, such as a BMP, is added to a suitable tissue source. The tissue source may be an osteochondral graft, either autologous to the patient, or may comprise allograft or artificially prepared tissue. In a preferred embodiment, the tissue source may be chondrocytic cell cultures, such as chondrocyte or stem cell cultures which have been prepared through *ex vivo* cell culture methods, with or without additional growth factors. For example, see the disclosure of US5226914; US5811094; US5053050; US5486359; US5786217 and US5723331. The disclosures of 30 all of these applications are hereby incorporated herein by reference.

The tissue may also be harvested by traditional non-cell culture based means, using techniques such as mosaicplasty, in which cartilage is harvested using commercially

5 available instruments such as Acufex7 [Smith and Nephew, Inc., Andover MA]; COR
System [Innovative Technologies, Marlborough MA]; or Arthrex7 Osteochondral
Autograft Transfer System [Arthrex, Munich, Germany]. The tissue harvested may be
applied directly in the methods of the present invention, or may be combined with the
tissue based cell culture systems described above.

10

GROWTH FACTOR

The active growth factor used in the present invention is preferably from the subclass of proteins known generally as bone morphogenetic proteins (BMPs), which have been disclosed to have osteogenic, chondrogenic and other growth and differentiation type activities. These BMPs include rhBMP-2, rhBMP-3, rhBMP-4 (also referred to as rhBMP-2B), rhBMP-5, rhBMP-6, rhBMP-7 (rhOP-1), rhBMP-8, rhBMP-9, rhBMP-12, rhBMP-13, rhBMP-15, rhBMP-16, rhBMP-17, rhBMP-18, rhGDF-1, rhGDF-3, rhGDF-5, rhGDF-6, rhGDF-7, rhGDF-8, rhGDF-9, rhGDF-10, rhGDF-11, rhGDF-12, rhGDF-14. For example, BMP-2, BMP-3, BMP-4, BMP-5, BMP-6 and BMP-7, disclosed in United States Patents 5,108,922; 5,013,649; 5,116,738; 5,106,748; 5,187,076; 15 and 5,141,905; BMP-8, disclosed in PCT publication WO91/18098; and BMP-9, disclosed in PCT publication WO93/00432, BMP-10, disclosed in United States Patent 5,637,480; BMP-11, disclosed in United States Patent 5,639,638, or BMP-12 or BMP-13, disclosed in United States Patent 5,658,882, BMP-15, disclosed United States Patent 5,635,372 and BMP-16, disclosed in co-pending patent application serial number 20 08/715,202. Other compositions which may also be useful include Vgr-2, and any of the growth and differentiation factors [GDFs], including those described in PCT applications WO94/15965; WO94/15949; WO95/01801; WO95/01802; WO94/21681; WO94/15966; WO95/10539; WO96/01845; WO96/02559 and others. Also useful in the present invention may be BIP, disclosed in WO94/01557; HP00269, disclosed in JP Publication 30 number: 7-250688; and MP52, disclosed in PCT application WO93/16099. The disclosures of all of these applications are hereby incorporated herein by reference. Also useful in the present invention are heterodimers of the above and modified proteins or

5 partial deletion products thereof. These proteins can be used individually or in mixtures of two or more, and rhBMP-2 is preferred.

The BMP may be recombinantly produced, or purified from a protein composition. The BMP may be homodimeric, or may be heterodimeric with other BMPs (e.g., a heterodimer composed of one monomer each of BMP-2 and BMP-6) or with other 10 members of the TGF- β superfamily, such as activins, inhibins and TGF- β 1 (e.g., a heterodimer composed of one monomer each of a BMP and a related member of the TGF- β superfamily). Examples of such heterodimeric proteins are described for example in Published PCT Patent Application WO 93/09229, the specification of which is hereby incorporated herein by reference. The amount of osteogenic protein useful herein is that 15 amount effective to stimulate increased osteogenic activity of infiltrating progenitor cells, and will depend upon the size and nature of the defect being treated, as well as the carrier being employed. Generally, the amount of protein to be delivered is in a range of from about 0.05 to about 1.5 mg.

In a preferred embodiment, the osteogenic protein is administered together with 20 an effective amount of a protein which is able to induce the formation of tendon- or ligament-like tissue. Such proteins, include BMP-12, BMP-13, and other members of the BMP-12 subfamily, as well as MP52. These proteins and their use for regeneration of tendon and ligament-like tissue are disclosed in United States application serial number serial number 08/362,670, filed on December 22, 1994, the disclosure of which is hereby 25 incorporated herein by reference. In another preferred embodiment, a heterodimer in which one monomer unit is an osteogenic protein such as BMP-2, and the other monomer subunit is a tendon-inducing protein, such as BMP-12, is administered in accordance with the methods described below, in order to induce the formation of a functional attachment between connective tissue and bone.

APPLICATION OF GROWTH FACTOR

Growth factor may be applied to the tissue source in the form of a buffer solution. One preferred buffer solution is a composition comprising, in addition to the active growth factor, about 1.0 to about 10.0% (w/v) glycine, about 0.1 to about 5.0% (w/v) of a sugar, preferably sucrose, about 1 to about 20 mM glutamic acid hydrochloride, and 10 optionally about 0.01 to about 0.1% of a non-ionic surfactant, such as polysorbate 80. Preferred solutions are from about 1% to about 20% w/v cellulosic carrier/buffer. If desired, a salt may be added.

Other materials which may be suitable for use in application of the growth factors in the methods and compositions of the present invention include hyaluronic acid, surgical 15 mesh or sutures, polyglyconate, temperature-sensitive polymers, demineralized bone, minerals and ceramics, such as calcium phosphates, hydroxyapatite, etc., as well as combinations of the above described materials. In the preferred embodiment of the present invention, however, no carrier is employed.

The growth factor of the present invention, in a suitable buffer such as that 20 described above, or combined with a suitable carrier, may be applied directly to the tissue and/or to the site in need of tissue repair. For example, the growth factor may be physically applied to the tissue through spraying or dipping, or using a brush or other suitable applicator, such as a syringe for injection. Alternatively, or in conjunction, the protein may be directly applied to the site in need of tissue repair.

25 The following examples further describe the practice of embodiments of the invention with BMP-2. The examples are not limiting, and as will be appreciated by those skilled in the art, can be varied in accordance with the above specification.

I. Rabbit Allograft

All procedures were carried out with approval from IACUC. Twelve male New Zealand white rabbits (6 months old) were used. Two rabbits served as donors and 10 as recipients. Osteochondral grafts (3.5 mm diameter) were harvested from the trochlear groove or the medial femoral condyle of the donors, and transplanted into a 3.5 mm deep defect in the trochlear groove of the recipient. The graft was bathed in either rhBMP-2 (0.5 mg/ml) or buffer control prior to implantation. The rabbits were sacrificed 4 weeks after surgery and the transplants and surrounding tissue were evaluated by a histologic-histochemical grading scale, as described in Sellers et al., *J. Bone Joint Surg.*, 79-A:1452-1463 (1997). Computerized image analysis of histologic sections was also performed. Results were evaluated using the unpaired Students t-test.

On gross examination, the joints showed no signs of inflammation. All the defects were filled by repair tissue. The surface appearance of the defects was variable but acceptable and did not correlate with form of treatment. Osteophytes were found in 3 joints (2 in the experimental group; 1 in control buffer group).

There was no correlation between the gross and histologic appearance in any of the defects. The presence of chondrocytes in the lacunae and sporadic cloning of cells in the donor cartilage indicated survival of the tissue. Focal degeneration of the donor cartilage was present in all of the control groups, but only one of the rhBMP-2 treated group. The healing of the defect in the rhBMP-2 treated group was significantly improved compared to that in the control group. The rhBMP-2 treated group had improved bony integration indicated by less fibrous repair tissue in the subchondral bone compartment. Treatment with rhBMP-2 also resulted in more cartilage above the original tidemark, apparently consisting of both donor tissue and newly regenerated recipient cartilage. There was no significant difference in the total amount of bone observed between the two groups.

TABLE I
HISTOLOGIC SCORE AND HISTOMORPHOMETRIC MEASUREMENT
FOR CARTILAGE REPAIR, MEAN VALUE (SD)

Parameter	rhBMP-2	Control
Average Score**	10.0(5.42)*	20.6(5.18)
% of bone under tidemark	73.26 (13.28)	62.88 (18.07)
% of fibrous tissue under tidemark	2.19 (2.04)*	15.81 (9.88)
% of cartilage above tidemark	74.70 (41.08)*	18.17 (26.70)
% of filling of the defect	96.53 (4.86)*	88.79 (8.04)

* Statistically significant difference from control ($p < 0.05$).

** Scale system ranges from 0 (normal cartilage) to 31 (no repair).

Additional histomorphometric analysis data further supports the beneficial effects of rhBMP-2 on the healing of graft. For example, the percentage filling of the new tissue above tide marker has been shown to be 81.52% in a rhBMP-2 treated group vs. 57.63% in control. There was less graft cartilage degeneration in rhBMP-2 treated group (23.83%) than in control group (44.52%). The integration of the graft or newly formed cartilage with the host cartilage was improved by rhBMP-2 treatment (56.48%) compared to that of control group (21.89%). More new cartilage formed under the influence of rhBMP-2 either at the edge of graft, which eliminated the gap between the graft and host, or at the top of graft, which made the graft more congruent with the joint surface.

30 The above results demonstrate that the healing of allogeneic osteochondral grafts in articular cartilage defects was improved by the addition of rhBMP-2. The active growth factor may have accelerated subchondral bone union, providing support and nutrition to the articular cartilage tissue. Addition of growth factor may also have stimulated new cartilage formation from recipient mesenchymal stem cells in the bone marrow and/or the synovial tissue. These results suggest that the combination of

5 active growth factor, particularly the bone morphogenetic proteins, and osteochondral allografts might present a potent strategy for treatment of articular cartilage defects, particularly full thickness articular cartilage defects.

II. Rabbit Autograft

10 Osteochondral grafts (2.7 mm in diameter and 3.0 mm long) were harvested from the trochlear groove or femoral condyle and transplanted into a donor site 2.7mm wide and 3.5mm long on the trochlear groove or femoral condyle of the knee joint in rabbits. Half the animals had buffer dripped into the recipient site prior to transplantation, and then the grafts were dipped in buffer for 2 minutes and placed into the recipient site. The other half had 5 μ g rhBMP-2 dripped into the recipient site prior 15 to transplantation, and then the graft was dipped into buffer containing 500 μ g/ml rhBMP-2 for 2 minutes and then transplanted into the recipient site. The animals were sacrificed 4 weeks after surgery, and the recipient sites were evaluated histologically using both a histologic-histochemical grading scale [Sellers, et al., J. Bone Joint Surg., 79-A: 1452-63 (1997)] and quantitative computerized image analysis of the tissue.

20 The data indicated that treatment with rhBMP-2 improved the healing of the autograft. The most dramatic effects were the reduction of graft cartilage degeneration (rhBMP-2 8.18% vs. control 36.25%), and more cartilage formed at the edge of graft (rhBMP-2 88.23% vs. control 50%).)

III. Non-Human Primate Autograft:

25 The non human primates used for autografts experiments were cynomolgous macaques. Osteochondral grafts (3.5mm diameter x 6mm long) were harvested from the trochlear groove of 6 cynomolgous macaques and transplanted into recipient sites drilled into both the medial and lateral femoral condyle of the same animal (n=12 transplants total). Prior to transplantation 25 μ g rhBMP-2 was dripped into 6 recipient 30 sites, and the grafts from those 6 transplants were dipped into a solution of 1.25mg/ml rhBMP-2 for 2 minutes. In the other 6 transplants, buffer alone was dripped into the

5 recipient sites and the grafts were dipped into buffer alone for 2 minutes prior to transplantation. The limbs were immobilized in a cast for 2 weeks post-operatively, and the animals were sacrificed 9 weeks post operatively.

All the animals had normal function of their knee joints. On gross examination, the joints showed no signs of inflammation. Osteophytes were not found in any joint.

10 Although the surface of the defects appeared level with the surrounding cartilage on gross examination, microscopic observation revealed subsidence of the grafts in most of the cases. The tissue observed grossly covering the surface was actually new-formed tissue on the top of graft. Computerized image analysis was performed by a blinded evaluator to quantitate percent filling of the defect, the new tissue types formed above

15 the original tide mark, and the integration of the grafts and the surrounding cartilage. Favorable results were observed in the rhBMP-2 treated group in all these parameters. More new cartilage formed between the graft and host cartilage to eliminate the gap resulting in better integration of the graft with the surrounding cartilage (rhBMP-2 88.59% vs. control 64.82%). The filling of the cartilage defect was better in rhBMP-2

20 treated group (95.02%) than in the control group (86.68%). There was more fibrous tissue in the control group (11.90% vs. rhBMP-2 5.65%), while more transitional tissue was found in the rhBMP-2 treated group (36.38% vs. control 20.53%). There

25 was no significant difference on the overall histologic-histochemical score between the two groups. Peripheral quantitative computered tomography (pQCT) showed that the bone density increased in the donor sites with time. At 6 weeks and 9 weeks after the operation, the tissue in the rhBMP-2 treated donor sites was significantly denser and the healing process was more advanced compared to control sites. Histologically, the donor sites contained regenerated bone trabeculae with fibrous tissue at the surface in all the cases.

30 **IV. rhBMP-2 Retention Ex Vivo:**

Retention of rhBMP-2 in osteochondral graft with this technique was evaluated with the grafts from non-human primates. The graft was dipped in a mixture solution

5 of ^{125}I labeled rhBMP-2 and unlabeled rhBMP-2. Results showed that the amount of rhBMP-2 absorbed to graft was proportional to the concentration of the protein, and the time of soaking. Other factors, which affect the retention of rhBMP-2, included the size of graft, and the presence of marrow elements between trabecular bone.

V. rhBMP-2 Retention Time Course In Vivo:

10 The time course of rhBMP-2 retention in osteochondral graft was evaluated in rabbits. A mixture solution of ^{125}I labeled rhBMP-2 and unlabeled rhBMP-2, which contained 5 ug rhBMP-2 and 20 uCi ^{125}I , was loaded to the graft before implantation. The animals were scanned with γ -camera during the follow-up time for 22 days post-operatively. Compared to the time course of collagen sponge as a carrier, the half time 15 of rhBMP-2 in osteochondral graft was increased from 1 day to 3 days. The radioactivity of 10% of the starting point was maintained from 11 days of collagen sponge to 22 days of graft.

VI. Non-Human Primate Allografts:

20 Donor sites (3.5 mm wide x 6 mm long) were removed from the trochlear grooves of 12 adult cynomolgous macaques and transplanted into 3.5 x 6mm recipient sites in the medial and lateral femoral condyles of unrelated individuals. Half of the transplants were soaked in 1.25 mg/ml rhBMP-2 for 2 minutes prior to transplantation, and half were soaked in buffer. The identical procedure was performed on the other limb 7 weeks after the first surgery. The limb was immobilized 25 in a cast for 2 weeks post operatively after each surgery, and the animals were sacrificed 9 weeks after the second surgery for histologic analysis.

30 These results suggest that the combination of active growth factor, particularly the bone morphogenetic proteins, and osteochondral autografts might present a potent strategy for treatment of articular cartilage defects, particularly full thickness articular cartilage defects.

5 In other embodiments BMP-2 may also be applied to frozen osteochondral
allograft for treatment of focal articular cartilage defect.

The foregoing descriptions detail presently preferred embodiments of the
present invention. Numerous modifications and variations in practice thereof are
expected to occur to those skilled in the art upon consideration of these descriptions.
10 Those modifications and variations are believed to be encompassed within the claims
appended hereto.

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CLAIMS

We claim:

1. A method for regeneration of articular cartilage comprising administering to an area in need of regeneration of said articular cartilage at least one purified bone morphogenetic protein (BMP).
- 10 2. A method for regeneration of articular cartilage comprising administering to an area in need of regeneration of said articular cartilage a suitable tissue source in combination with at least one purified bone morphogenetic protein (BMP).
3. The method of claim 1 wherein said BMP is BMP-2
4. The method of claim 2 wherein said BMP is BMP-2.
- 15 5. A method for regeneration of articular cartilage comprising administering to an area in need of regeneration of said articular cartilage at least one purified protein selected from the group consisting of Vgr-2, growth and differentiation factors (GDFs), and BIP.
6. The method of claim 1 further comprising a protein which induces the formation of tendon or ligament-like tissue.
- 20 7. The method of claim 6 wherein said protein which induces the formation of tendon or ligament-like tissue is selected from the group consisting of BMP-12, BMP-13 members of the BMP-12 subfamily and MP52.
8. A composition for regeneration of articular cartilage said composition comprising at least one purified bone morphogenetic protein (BMP).
- 25 9. A composition for regeneration of articular cartilage said composition comprising a suitable tissue source in combination with at least one purified bone morphogenetic protein (BMP).

10. The composition of claim 8 wherein said BMP is BMP-2

11. The composition of claim 9 wherein said BMP is BMP-2.

12. A composition for regeneration of articular cartilage said composition comprising at least one purified protein selected from the group consisting of Vgr-2, growth and differentiation factors (GDFs), and BIP.

10 13. The composition of claim 8 further comprising a protein which induces the formation of tendon or ligament-like tissue.

14. The composition of claim 13 wherein said protein which induces the formation of tendon or ligament-like tissue is selected from the group consisting of BMP-12, BMP-13 members of the BMP-12 subfamily and MP52.

ABSTRACT

Methods and compositions are provided for the treatment of articular cartilage defects and disease involving the combination of tissue, such as osteochondral grafts, with active growth factor. The active growth factor is preferably a composition containing at least one bone morphogenetic protein and a suitable carrier. The method 10 results in the regeneration of functional repair of articular cartilage tissue.

DECLARATION and POWER OF ATTORNEY

As a below-named inventor, I hereby declare that:

My residence, post office address, and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

METHODS AND COMPOSITIONS FOR HEALING AND REPAIR OF ARTICULAR CARTILAGE

the specification of which

(check one) is attached hereto.

was filed on _____ as
Application Serial No. _____
and was amended on _____.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information of which I am aware which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, Section 1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s)

<u>Number</u>	<u>Country</u>	<u>Filing Date</u>	<u>Priority Claimed</u>
_____	_____	_____	YES/NO
_____	_____	_____	YES/NO

I hereby claim the benefit under Title 35, United States Code, Section 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, Section 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, Section 1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

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Kevin M. Flanagan
Name of Signing Person

I hereby appoint the following attorneys to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith:

Ellen J. Kapinos, Reg. No. 32,245; Suzanne A. Sprunger, Ph.D., Reg. No. 41,323; Barbara A. Gyure, Reg. No. 34,614; all of 87 Cambridge Park Drive, Cambridge, Massachusetts 02140; and
Egon E. Berg, Reg. No. 21,117; Elizabeth M. Barnhard, Reg. No. 31,088; Gale F. Mathews, Reg. No. 32,269; Alan M. Gordon, Reg. No. 30,637; Darryl L. Webster, Reg. No. 34,276; all of One Campus Drive, Parsippany, New Jersey 07054; and
Rebecca R. Barrett, Reg. No. 35,152; Steven R. Eck, Reg. No. 36,126; Arnold S. Milowsky, Reg. No. 35,288; Michael R. Nagy, Reg. No. 33,432; Arthur G. Seifert, Reg. No. 28,040; George Tarnowski, Reg. No. 27,472; all of P.O. Box 8299, Philadelphia, Pennsylvania, 19101; and
Robert F. Boswell, Jr., Reg. No. 35,072 of P.O. Box 26609, Richmond, Virginia 23261-6609; and
Address all telephone calls to Barbara A. Gyure at Telephone No. (617) 665-8653. **Address all correspondence to American Home Products Corporation, Patent & Trademark Department - 2B, Attn: Kay E. Brady, One Campus Drive, Parsippany, New Jersey, 07054.**

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full name of sole or first inventor Renwen Zhang

Inventor's signature

Date _____

Residence 359 Veterans Blvd., Rutherford, New Jersey 07070

Citizenship USA

Post Office Address 359 Veterans Blvd., Rutherford, New Jersey 07070

Full name of second joint inventor Diane Peluso

Inventor's signature _____

Date

Residence 107 Emery Road, Marshfield, MA 02050

Citizenship USA

Post Office Address 107 Emery Road, Marshfield, MA 02050

Full name of third joint inventor **Elisabeth Morris**

Inventor's signature

Date

Residence 15 Apple Street, Sherborn, MA 02155

Citizenship USA

Post Office Address: 15 Apple Street, Sherborn, MA 02155